

Citation for published version:

Chen, Q, Hammond, G & Norman, J 2015, 'Contrasting Thermodynamic, Technical and Economic Potentials: The Example of Organic Rankine Cycle Use within UK Industry', *Energy Procedia*, vol. 61, pp. 225-229.
<https://doi.org/10.1016/j.egypro.2014.11.1094>

DOI:

[10.1016/j.egypro.2014.11.1094](https://doi.org/10.1016/j.egypro.2014.11.1094)

Publication date:

2015

Document Version

Publisher's PDF, also known as Version of record

[Link to publication](#)

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The 6th International Conference on Applied Energy – ICAE2014

Contrasting thermodynamic, technical and economic potentials: The example of organic Rankine cycle use within UK industry

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Abstract

The laws of thermodynamics set a theoretical limit on the energy savings that can be realised in a given application. This thermodynamic potential cannot be reached in practice, and a technical potential for energy savings is defined by the performance of available technology. Only applications of the technology that are considered economic will usually be considered for installation. This economic potential will itself not be fully realised, with the actual savings achieved limited by further barriers. A database on surplus heat availability within UK industry was used to estimate the thermodynamic, technical, and economic potentials when converting this surplus heat to electricity using organic Rankine cycles (ORCs). Technical and economic information was based on that reported from existing installations and manufacturers. Various parameters, such as the local price of electricity, are subject to considerable uncertainty, and so a range of possible scenarios were investigated. The results form a basis for discussion on how to close this “gap” between the identified potentials and the savings realised.

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Keywords: Surplus heat; Energy efficiency gap; Organic Rankine cycle; Industry; Barriers; Manufacturing.

1. Introduction

Surplus heat arises from many processes within industry [1]. One potential use of this heat is its conversion to electricity [2]. Organic Rankine cycles (ORCs) are the most well established technology for converting heat that is available at too low a temperature for the use of traditional, water-based, electricity generation technology. A dataset detailing the surplus heat available at industrial sites in the UK was

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available from previous work [1, 2]. This covered those sites involved in the EU Emissions Trading System (EU ETS). Thermodynamic laws, ORC manufacturer information, and wider economic parameters were used to estimate the thermodynamic, technical and economic potential for ORC systems at the sites in this dataset.

2. Methodology

A number of parameters were used in the calculation of the present results, and these are briefly discussed here. Due to the uncertainty associated with many of these parameters, three cases were analysed: the mean case, a best case scenario, and a worst case scenario. Where the range of a parameter is given in brackets this represents its minimum and maximum values.

- For each site in the study the temperature of surplus heat, the load factor of the site and the magnitude of the surplus heat source (which was given as a range) was taken from previous work [2].
- The temperature of surplus heat that could be utilised by ORC equipment was taken as 80–400°C, and the minimum power output was set as 50kW_e, based on information from a number of manufacturers[†]. A number of different operating fluids would be used over this temperature and power range.
- The efficiency of ORC equipment, in converting surplus heat to electricity, varies with temperature. The Carnot efficiency sets the thermodynamic limit (an environment temperature of 25°C was assumed). The actual efficiency was based on that reported by manufacturers and in case studies [3–8]. A logarithmic trend line was fit to the efficiency data, maximum and minimum efficiencies were calculated in a similar manner.
- The specific investment (or capital) cost of the equipment (£2012/kW_e) varied with the power output. Based on manufacturer information, and case studies [9–11], and using relevant conversion factors, a logarithmic trend line was fit to the investment cost data, maximum and minimum costs were calculated in a similar manner.
- Other costs, including operation and maintenance costs, and insurance were estimated as 5.25% (1.5–9%) of the investment costs per annum.
- Electricity output was assumed to offset that purchased from the grid. Electricity price was taken from government projections[12], which estimated the future retail price for industry, including taxes, out to 2030. Central, low price, and high price scenarios were used to represent the mean, best, and worst cases respectively. The year of installation was taken as 2013.
- The commercial discount rate used in calculations was assumed to be 10% (5–15%).
- The lifetime of ORC equipment was estimated as 20 years (15–25 years).
- The target payback period, to be economically attractive, was presumed to be 3 years (1–5 years).

The thermodynamic potential was calculated, using the Carnot efficiency. Technical potential was based on the calculated efficiencies detailed above, and the minimum ORC size. The payback period for the equipment was calculated using the above parameters under the mean, best and worst case scenarios.

3. Results

Fig 1 shows the calculated thermodynamic, technical, and economic potential for the installation of ORC systems at the UK industrial sites in this study; the annual electricity output is shown. Two cases of

[†] Manufacturer information used in this study covered: Turboden, Cryostar, ElectraTherm, Freepower, GMK, Triogen, Pratt & Whitney, Barber-Nichols, TransPacific Energy, and Infinity Turbine. Not all manufacturers provided information on every parameter.

economic potential are shown: whether the equipment will payback over its expected lifetime, and whether it would payback within the target period (referred to as “economically attractive” in Fig. 1). The error bars represent the combination of parameters that gave best and worst case scenarios. All sites assessed were economic over the expected lifetime of the equipment, however this was not necessarily the case if equipment must pay back within an “attractive” timescale. This finding is sensitive to the input parameters, under the best case all projects are economically attractive, whilst in the worst case scenario there were no economically attractive projects. In the mean case, the economically attractive potential comprises a relatively small number of sites (22) that have large supplies of surplus heat (in total there were 425 sites in the analysis dataset, 376 of them with surplus heat sources in the temperature range of interest). ORC equipment becomes economically attractive with higher electricity outputs. This is dependent on site specific parameters, the temperature and magnitude of surplus heat available, and the load factor of the site operations.

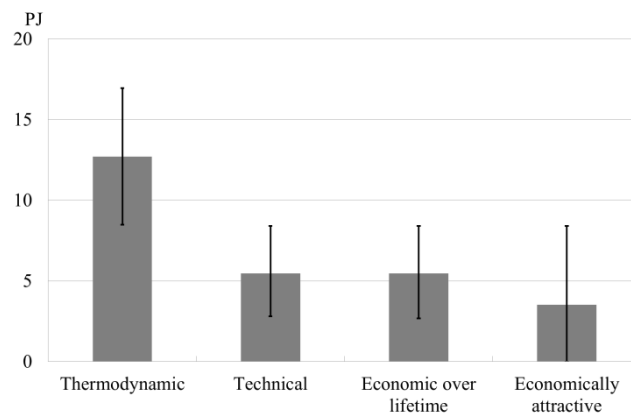


Fig 1. Thermodynamic, technical and economic potential. Electricity output per annum from ORC systems.

4. Concluding remarks

There was a substantial gap identified between the thermodynamic and technical potential for ORC equipment. Future developments in technology can act to close this gap. The thermodynamic potential can be approached, but it cannot be reached in practice. Technical barriers not identified here, such as a lack of space for ORC equipment, may also exist. Although all opportunities identified were economic over the expected equipment lifetime these would not all be expected to be taken up. The economically attractive measure is an estimation of what opportunities might be realised in practice, but there are company and site specific barriers that can influence this. There are other potential technologies that can reuse surplus heat [2], and these may be more attractive from a technical, or economic, perspective. Although a conservative approach was adopted in estimating costs, the assorted costs may not be complete. For example the presence of corrosive elements in the fluid heat source may add additional costs, unaccounted for here. A company will have its own preferred measures of economic viability, and there is a range of potential additional barriers, including: a lack of information relating to the savings potential, a focus on production issues, a lack of capital, lack of staff time or skills, hidden costs, perceived risks, a limited window of opportunity to install equipment, and split incentives between the instigator of the project and the profiteer [13]. There may also be additional drivers for the projects not accounted for here, these might include: future energy costs and legislation; the desire to insulate a site from electricity price fluctuations; other indirect benefits,

such as fulfilling corporate social responsibility (CSR) objectives; and the presence of an individual champion for energy issues holding a decision making position within the company [13].

Acknowledgements

The present research forms part of a wider programme on industrial energy demand and carbon emissions reduction that was initially supported by *UK Energy Research Centre* (UKERC); Phase II renewed in 2009 [under Grant NE/G007748/1]. More recently this work has been funded by the *UK Engineering and Physical Sciences Research Council* as part of the UK INDEMAND Research Centre [under Grant EP/K011774/1]. The Principal Investigator at the University of Bath for both grants was the second author (GPH), whilst the third, corresponding author (JBN) held the associated post of Research Officer (now Fellow). All the authors wish to thank the Heat Group of the *Energy Technologies Institute* (ETI) for encouraging the original research that formed the dataset for this paper.

Authors' names appear alphabetically.

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Biography

Dr. Jonathan Norman is a Research Fellow at the University of Bath. He is currently part of the UK INDEMAND Centre, which aims to reduce industrial energy and material use in supplying UK needs. Previously he has worked on issues regarding industrial energy for the UK Energy Research Centre.